# EVALUATION OF HIGHWAY ROUGHNESS IN BOLIVIA

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Highway roughness measurements were made in Bolivia in the Districts of La Paz, Cochabamba, and Santa Cruz (1) using a Mays Ride Meter. The work was sponsored by the International Bank for Reconstruction and Development (IBRD) as part of a pavement maintenance project with the Servicio Nacional de Caminos, Bolivia (7). Several measurement results are presented. These include Mays Meter calibration results using the TRRL pipe course, both prior to and after completion of a large survey. Roughness survey results are compared to results obtained in Kenya. Roughness versus speed information taken during the calibration and roughness measurements from paved, gravel, and earth roads are presented. The effectiveness of motor-grader operations in reducing roughness is discussed. A preliminary roughness scale developed for use in Bolivia is presented and compared with a Kenya roughness scale developed by the IBRD (8). Conclusions drawn from the paper include the establishment of tentative roughness limits for roads in Bolivia and similar countries. The measurements obtained were successfully used with IBRD maintenance cost models, thus assisting the maintenance programming in Bolivia. Since the completion of the work presented in this paper, further measurements have been made for planning and study purposes.

## Background

The International Bank for Reconstruction and Development (IBRD) uses models developed from a Kenya study to relate user cost to road roughness (8). Unfortunately there are significant problems involved in determining road roughness in other countries and scaling the resulting values to the Kenya equations. The purpose of this study was to establish compatibility between various methods of evaluating pavement roughness on a world-wide basis. Texas Research and Development Foundation (TRDF) conducted this study in 1978 for IBRD and the Servicio Nacional de Caminos (SNC) of Bolivia.

The objectives of the project were:

1. To provide a basis for development of a general roughness index (7) which can potentially be used for world wide roughness comparison,
2. To obtain roughness data on selected section of Bolivian highways for input into IBRD maintenance cost models, which use a Kenya-based roughness index,
3. To measure the effectiveness of motor-grader maintenance operations in smoothing gravel and earth roads,
4. To establish a roughness measuring capability for SNC use in Bolivia, and
5. To train SNC personnel in the installation, calibration, and use of roughness measurement equipment.

A Mays Ride Meter with two different roughness devices was used in the study; (1) an electronic digital system and (2) an electromechanical paper output system. The paper output system is manufactured by Rainhart Company (2), while the electronic digital system has been developed on an IBRD project in Brazil (3, 4, 5, 6). The Mays Ride Meter paper output contains three traces; (1)pavement roughness, (2) an odometer distance marking, and (3) a special event trace controlled by the operator. The paper chart flow is a function of the roughness measured and this feature allows roughness to be summed continuously. The electronic summary equipment uses the Mays Meter roughness transmitter manufactured by Rainhart. However, it uses a digital distance measuring instrument (6) which sums roughness over 50 m (165 ft.) or 200 m (660 ft.) intervals (3, 4, 5). The Mays Meter transmitter is mounted in the rear of the vehicle over the differential. The measurement vehicle for this study was a 1976 Chevrolet Suburban, which has a relatively stiff suspension.

The primary scope of the project included sampling a total of 1300 km (780 mi.) of roadway, approximately one-third of which was in each of the three Districts: La Paz, Cochabamba and Santa Cruz, as shown in Figure 1. Table 1 shows a breakdown of the sites according to location and road type. Roughness measurements were also made on fourteen unpaved roads prior to and after the passage of a standard motor-grader. Calibration sections were established in Bolivia to facilitate maintenance and calibration of the roughness measurement devices. A Transport and Road Research Laboratory (TRRL) pipe calibration section (8) was established on a portland cement concrete road at the El Alto Airport in La Paz. Calibration sections were also established on in-service roadways in all three districts.

## Equipment Calibration

Initially the Mays Ride Meter was calibrated on the TRRL calibration strip which was established in La Paz. The joint spacing of this pavement is 6 m (20 ft.), and the pavement is 10 cm (4 in.) thick with .635 cm (.25 in.) diameter mesh steel reinforcement. There is a granular base of varying thickness and a granular subgrade soil with little plasticity. Thus, the roughness of the basic section should remain stable for many years.

The development of the pipe course is reported by Abaynayaka et al, (8). Measurements are taken for six different states or levels of roughness simulating virtually the full range of roughness, from a paved road in good condition to an unpaved road in extremely poor condition. The procedure consists of establishing a permanent test section on a rigid concrete pavement with a number of pipe segments (from 0 to 150) bolted across the vehicle wheelpaths at varying intervals to simulate varying stages of roughness. The vehicle and instrument make three passes over the test section in each state of roughness to establish the calibration. The pipes are 2.2 m (7.25 ft.) long with an external diameter of 33.9 mm (.38 in.). The six different states of roughness are given as follows: (Note - 1 m = 3.3 ft.)

Stage I No pipes.

Stage II 25 pipes, placed at points 0, 12, 24, etc., to 288 m.

Stage III 25 additional pipes, placed at 8, 20, 32, etc., to 296 m.

Stage IV 25 additional pipes, placed at 4, 16, 28, etc., to 292 m.

Stage V 39 additional pipes, placed at 2, 6, 10 26, 30, 34, 50, 54, 58, etc., to 290, 294, 298 m.

Stage VI 36 additional pipes - to fill all spaces at 2 m intervals.

Table 2 summarizes the results from the calibration course with the electronic equipment, which was used in the sampling measurements due to its data presentation format. Initially (July 8), the calibration was done at 30 km/hr (20 mph), as recommended by TRRL. Subsequently (July 13), the device was calibrated at speeds of 20, 30, and 50 km/hr (12, 20, and 32 mph) to facilitate comparison of Bolivian measurements with measurements currently being made on a Brazilian project (3) and to establish speed correlations. The maximum percent difference between July 8 and July 13 30 km/hr (20 mph) calibrations was 11 percent. This is close, considering that on a given pavement it is normal to have variations of 10 to 15 percent in average roughness readings from one day to another. The measurement repeatability is also good: the average coefficient of variation of these measurements is 3 percent. On August 8, upon completion of sampling measurements, the electronic equipment was recalibrated on the TRRL calibration course. Those mean values are also shown in Table 2, with their percent change as compared to the calibrations of July 13. Again, the calibrations compare well, except for two 20 km/hr (12 mph) comparisons which are greater than 15 percent. This difference, however, is not abnormal because at slower speeds the roughness is more variable, depending upon wheel path, tire pressure, and weight of the measurement vehicle. However, comparison of the other calibrations indicates that the equipment remained in calibration for the measurement period.

Figure 2 shows the speed correction relationships developed for the different calibration speeds using the electronic device data. In general roughness decreased with speed. Also, at 50 km/hr (30 mph) the roughness-stage relationship is linear. These relationships were used to calibrate roughness measurements taken at one speed to equivalent roughness values for other speeds, which may have been impossible to take due to alignment, dust, etc. Additional roughness data taken at different speeds on in-service roadways are contained in Table 3, which also shows the magnitude of the coefficient of variation which may occur during the sampling of a given roadway. The data are plotted in Figure 3, indicating that, in general, roughness decreases with speed.

Because of the differences in data presentation by the paper and electronic devices, a method was established to transform the output of both systems into identical comparable units,. i.e., millimeters of pavement roughness per kilometer of pavement length.

## Sampling of Inservice Highways

Thirteen paved roads, sixteen gravel roads and ten earth roads (1300 km, 780 mi.) were sampled. These were evenly distributed among the three Districts and were chosen by the SNC as representative examples of different highway types. Table 4 shows the results from the sampling of paved roadway sections. All paved roads measured were designated "primary highway" with the exception of two secondary roadways and one rural roadway. The mean roughness, standard deviation, and coefficient of variation of the measurements on these various pavements are included in Table 4, along with pavement type, condition of the pavement in terms of a present serviceability rating (PSR), and pavement age in years. The Autopista, currently under construction between La Paz and the El Alto Airport, has the minimum mean roughness measured, 231 mm/km (15 in./mi.). The maximum mean roughness, 3,000 mm/km (200 in./mi.), was measured on Route 4 in the Santa Cruz District, which is 30 years old and has severe surface distress in the form of Class 3 AASHO cracking, edge failures, and numerous potholes. Figure 4 shows the relationship between present serviceability ratings (PSR) and roughness for the paved sections. The large coefficients of variation result from the fact that the roads are highly variable and the mean value for each road was obtained by sampling along the highway over distances varying from 30 km (20 mi.) (Santa Cruz to Warnes) to 123 km (74 mi.) (La Paz to Sica Sica). The reason for these measurements was to determine the roughness of the typical pavements over their length.

Table 5 summarizes the mean roughness values for the gravel roadway sections sampled. In some cases, the measurement speed was less than the desired 50 km/hr (30 mph) due to poor visibility from dust, alignment, grade and/or traffic. Therefore, the roughness was measured at a lower speed, either 20 or 30 km/hr (12 or 20 mph) and the roughness value was converted to an equivalent roughness value for a measurement speed of 50 km/hr (30 mph). The mean roughness for gravel roads varied from a low of 4,393 mm/km (293 in./mi.), which is for a good gravel road, probably graded less than one week prior to the measurement, to a high value of 14,986 mm/km (1,000 in./mi.) on a gravel road containing extensive washboarding and poor aggregate size distribution. The mean roughness for primary roads was 9,000 mm/km (600 in./mi.). The mean roughness for secondary roads was 8,100 mm/km (540 in./mi.) and the mean roughness for rural roads was 12,060 mm/km (804 in./mi.).

Table 6 summarizes the sampling measurements made on the earth roads, generally at a speed of 30 km/hr (20 mph) due to problems with dust, alignment, grade and/or roughness. The mean roughness for earth roadways varied from 7,600 mm/km (507 in./mi.) to 16,660 mm/km (1,111 in./mi.).

## Effectiveness of Motor-Grader Operations On Roughness

Measurements of the effectiveness of motor grading were carried out on gravel and earth sections. Table 7 shows the results of the grading experiments on gravel sections in the La Paz and Cochabamba Districts. As the before and after grading roughness measurements show, the roughness was improved on all sections except one. Three sections in the La Paz District, due to their proximity to the SNC office, were also measured one or two days later and twenty days later. Figure 5 shows that, in all three cases, within twenty days without maintenance these roads had returned to the condition observed before grading. In the case of Highway 1 near Laja, twenty days after the initial grading, with no additional maintenance, the road was worse than initially. This road is generally maintained more often than once in three weeks because it is a primary route.

Table 8 summarizes the grading experiments on earth sections. The roughness values in Table 8 are for a speed of 30 km/hr (20 mph) because most of the measurements on these earth roads were made at 30 km/hr (20 mph) or less. The earth roads had a much larger percentage reduction due to grading than did the gravel roads. In the case of Highway 1355, for example, there is a 66 percent reduction, with a before grading roughness of 19,000 mm/km (1267 in./mi.) and an after grading roughness of 6,460 mm/km (431 in./mi.). However, it must be understood that these roads will not maintain the after grading roughness for a long period of time.

The grading studies have shown that grading significantly lowers in the roughness of gravel and earth roadways. It is hoped that use of the roughness measurement equipment will assist SNC maintenance forces in determining schedules for grading equipment and other maintenance operations.

## Development of Bolivia Roughness Scale

Roughness measurements from the paved, gravel, and earth roads were summarized to obtain the overall range of roughness measured in Bolivia. The 30 km/hr (20 mph) mean roughness values were used to allow comparison with the Kenya scale(8). The mean roughness values varied from a low of 231 mm/km (15 in./mi.) on the new Autopista to a high of 22,000 mm/km (1467 in./mi.) on a gravel road with extremely poor aggregate gradation.

The TRRL roughness measurements in Kenya were made with a towed fifth wheel bump integrator (Similar to a B.P.R. Roughometer). Table 9 shows roughness values for both Bolivia and Kenya for various types of roadways. The overall range of roughness measured in the Kenya study was 1,429 to 20,600 mm/km (95 to 1,374 in./mi.). This roughness range corresponds closely to the roughness range measured in Bolivia at a comparable speed but with a different instrument.

The mean pavement roughness in Bolivia in 1,875 mm/km (125 in./mi.) with a standard deviation of 998 mm/km (67 in./mi.). The mean gravel road roughness in Bolivia is 13,850 mm/km (924 in./mi.), with a standard deviation of 4,631 mm/km (309 in./mi.). The mean roughness of earth roadways is 11,465 mm/km (765 in./mi.), with a standard deviation of 3,892 mm/km (260 in./mi.). When these data are compared to average Kenya roughness data the mean pavement value for Bolivia, 1875 mm/km (125 in./mi.), compares closely with the mean for all pavements measured in Kenya, 1800 mm/km (120 in./mi.) for asphaltic concrete, 2400 mm/km (160 in./mi.) for new surface dressed, and 2700 mm/km (180 in./mi.) for old surface dressed. The gravel and earth mean roughness values for Bolivia, 13,850 and 11,465 mm/km (924 and 765 in./mi.), respectively, compare well with the range of roughness measured on gravel roads in Kenya, 5000 mm/km (334 in./mi.) for gravel roads in good condition and 10,000 mm/km (667 in./mi.) for gravel roads in poor condition.

Therefore, we concluded that the ranges of roughness, in units of millimeters per kilometer, from the Kenya and Bolivian measurements were comparable. While the two devices have different operational characteristics, differences in variability and repeatability, and different output, it may be fairly concluded that the data collected in Kenya and Bolivia could be used with other data to produce a generalized roughness index (GRI) (7).

## Subsequent Measurements

In March, 1978, the SNC carried out a series of additional highway roughness measurements on roads representative of each highway type.

A Mays Ride Meter roughness electronic recording device (1) was used. The instrument, the vehicle, and the calibration section were the same as those used by TRDF in the 1977 study.

### Roughness Measurements Objectives

The study had the following main objectives:

1. To determine the differences between gravel and earth road roughness in the dry season (TRDF measurements) and those in the wet season (SNC measurements).
2. To determine the effect of motor-grader passes in smoothing gravel and earth roads in the wet season and to compare it with the dry season effect.
3. To increase the existing amount of highway roughness data in Bolivia, in order to fix maintenance standards and minimum desirable road surface conditions for each highway category.

### Equipment Calibration

Calibration was performed according to the TRRL calibration method, as described earlier in this paper. The Mays Ride Meter with an electronic recording device was calibrated at two different times March 3, 1978 before starting the field measurements and March 22, 1978 when the field measurements were completed. Calibration was carried out at speeds of 20, 30, and 50 km/hr (12, 20 and 30 mph). Table 10 summarizes the calibration results.

An analysis of Table 10 shows that the percentages of variation between the two calibration records are low and similar to those which were obtained from the TRDF calibration records. Therefore, we conclude that the TRDF and the SNC roughness measurement records are mutually comparable.

Regression analyses were done on these data in order to establish mathematical relationships between highway roughness measurements at 20 and 50 km/hr (12 and 30 mph) running speeds and 30 km/hr (20 mph) records. These curves and mathematical relationships are shown in Figure 6. Correlation coefficients are very high and standard errors are low, indicating that these relationships can be used to compare roughness records at different speeds. This capability is very important for the Bolivian conditions, since there are some roads which do not allow any speed higher than 20 km/hr.

## Highway Roughness Sampling Measurements

The most representative highways of each type, including paved, gravel, and earth roads, were selected in the three different areas of the country: the highlands (rolling and dry terrain), the valleys (rugged terrain, medium moisture content), and the flats (low lands, sub-tropical and humid weather).

Most sections are the same as those selected for the earlier TRDF project (see Figure 1).

Paved Highways. Sampling on paved highways was carried out on 500 m (1650 ft.) long sections distributed throughout the whole length of each road considered. Table 11 shows the results of this sampling.

Gravel and Earth Roads. Results of roughness sampling measurements on gravel roads are shown in Table 12. Also shown are the data derived from the TRDF measurements on gravel roads, in order to compare wet season and dry season figures. These data indicate that rainy season road roughness is usually lower than dry season roughness on the same roads. There are only two roads for which data do not agree with this conclusion and both are roads where maintenance is very poor.

Effectiveness of Motor-Grader on Unpaved Roads Roughness Reduction. Some locations were selected for measuring surface roughness before grading, and immediately after grading. On some of these test sections, surface roughness was measured again after different time periods in order to observe its variation. Table 13 shows results of these roughness measurements, as well as those from TRDF in the dry season. These figures suggest that motor-grader passes in the rainy season achieve a smaller percentage reduction in roughness than in the dry season. However, the absolute roughness value in the rainy season is lower than in the dry season.

## Summary

As a result of this project the Servicio Nacional de Caminos now has a pavement roughness measurement capability and trained personnel to undertake future studies. Roughness has been measured and summarized on representative paved, gravel, and earth roads of all classifications in three districts on a total of 1,300 km (780 mi.).

If the mean roughness plus one standard deviation is used as a point at which maintenance should be undertaken, the following limiting values should be criteria for the three roadway classifications:

1. Pavements - 2,873 mm/km (191 in./mi.)
2. Gravel - 18,841 mm/km (1,257 in./mi.)
3. Earth - 15,357 mm/km (1,024 in./mi.)

Based on these possible criteria, two paved sections fell outside the maintenance limitation while two gravel sections and two earth sections needed more blading at the time of measurement. These three limiting factors may, in fact, be too high. However, the amount of maintenance equipment available makes it difficult to grade the gravel and earth sections as often as desired. Some earth sections could be graded on a daily basis because of the heavy truck traffic present. Much of the roughness on gravel sections is due to the poor gradation of materials present.

Comparison of the Bolivian and Kenyan data indicates the feasibility of developing a generalized roughness index for world-wide use. This is a particularly desirable use for measurements such as those described. There is definitely a need to express roughness measurements in comparable terms so that data can be shared. The data obtained from

The data obtained from these measurements were successfully used by the IBRD in cost models (8) to evaluate the most effective maintenance expenditure on Bolivian roads. In addition, the measurements of motor-grader effectiveness on earth and gravel roads in both the dry and rainy seasons provide useful information concerning maintenance quality and scheduling.

The ability to schedule maintenance should be improved through the use of roughness measurement equipment. A measurement program can be undertaken and can help to determine the correct time intervals for grading on the various roadway classifications and to further define limiting criteria. It is shown by the motor-grader study that blading definitely lowers road roughness and a systematic blading program based on objective roughness measurements should help maintenance scheduling. Finally, the close comparison of 1977 and 1978 calibrations and measurements indicates the reliability of the Mays Meter equipment.

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Table 1. Location and Extent of Measurements

| | La Paz | Coch. | S. Cruz | Total |
|---|---|---|---|---|
| **Paved Roads** | | | | |
| Sections Sampled | 4 | 3 | 4 | 1[illegible] |
| Kilometers Sampled[a] | 185 | 235 | 243 | 663 |
| Calibration Sites | 4[b] | 2 | 1 | 7 |
| **Gravel Roads** | | | | |
| Sections Sampled | 8 | 4 | 2 | 14 |
| Kilometers Sampled | 204 | 133 | 21 | 358 |
| Grading Sections | 4 | 3 | 0 | 7 |
| **Earth Roads** | | | | |
| Sections Sampled | 2 | 3 | 5 | 10 |
| Kilometers Sampled | 30 | 21 | 198 | 249 |
| Grading Sections | 1 | 2 | 4 | 7 |
| **Summation** | | | | |
| Sections Sampled | 14 | 10 | 11 | 35 |
| Kilometers Sampled | 419 | 389 | 462 | 1270 |
| Grading Sections | 5 | 5 | 4 | 14 |

[a] 1 km = 0.62 mile

[b] Includes airport road/TRRL calibration section

Table 2. TRRL Calibration Course Roughness (1977)

| Stage[a] | Measurement Speed km/h | July 8 Electronic Mays Meter Device $\bar{x}$ mm/km | July 8 $\sigma$ mm/km | July 13 Electronic Mays Meter Device $\bar{x}$ mm/km | July 13 $\sigma$ mm/km | Percent Change,[b] % | August 8 Electronic Mays Meter Device $\bar{x}$ mm/km | August 8 $\sigma$ mm/km | Percent Change,[c] % |
|---|---|---|---|---|---|---|---|---|---|
| | 50 | | | 7493 | 84 | | 7745 | 670 | 3 |
| 6 | 30 | 10950 | 369 | 12271 | 369 | 11 | 12439 | 302 | 1 |
| | 20 | | | 16898 | 201 | | 20217 | 17 | 1 |
| | 50 | | | 6806 | 134 | | 6848 | 134 | 1 |
| 5 | 30 | 10025 | 101 | 9338 | 17 | -7 | 10653 | 553 | 12 |
| | 20 | | | 13646 | 503 | | 15297 | 587 | 11 |
| | 50 | | | 5348 | 50 | | 5544 | 50 | 4 |
| 4 | 30 | 6722 | | 6639 | 184 | -1 | 7628 | 17 | 13 |
| | 20 | | | 8684 | 67 | | 10813 | 385 | 19 |
| | 50 | | | 4359 | 101 | | 4442 | 134 | 1 |
| 3 | 30 | 5398 | 151 | 5432 | 17 | 1 | 5717 | 201 | 5 |
| | 20 | | | 6823 | 218 | | 7812 | 34 | 12 |
| | 50 | | | 3135 | 67 | | 3319 | 101 | 6 |
| 2 | 30 | 3721 | 67 | 3688 | 17 | -1 | 3872 | 151 | 5 |
| | 20 | | | 4241 | 67 | | 4526 | 17 | 6 |
| | 50 | | | 1877 | 101 | | 1945 | 151 | 3 |
| 1 | 30 | 1660 | 134 | 1504 | 151 | -9 | 1777 | 67 | 10 |
| | 20 | | | 1308 | 117 | | 989 | 67 | -24 |

[a] Stage 6 - 150 pipes, Stage 5 - 114 pipes, Stage 4 - 75 pipes, Stage 3 - 50 pipes, Stage 2 - 25 pipes, and Stage 1 - 0 pipes.

[b] July 13 compared to July 8.

[c] August 8 compared to July 13

Note: 1km/hr = .62 mph, 1mm = .04 in., 1 km = 0.62 mi.

Table 3. Roughness vs. Speed Data On Inservice Roadways

| Highway Type | Speed, km/hr | Mean Roughness, mm/km | Coefficient of Variation, % |
|---|---|---|---|
| Paved | 65 | 1092 | 44 |
| | 50 | 1346 | 45 |
| | 30 | 2286 | 25 |
| Paved | 50 | 2718 | 70 |
| | 30 | 3810 | 69 |
| Gravel | 80 | 3327 | 25 |
| | 65 | 6350 | 28 |
| | 50 | 8776 | 38 |
| | 30 | 15875 | 22 |
| | 20 | 12497 | 21 |
| Gravel | 50 | 12751 | 20 |
| | 30 | 12548 | 24 |
| | 20 | 12065 | 34 |
| Gravel | 50 | 8179 | 23 |
| | 30 | 14656 | 26 |
| | 20 | 21615 | 17 |
| Gravel | 50 | 4394 | 33 |
| | 30 | 7747 | 32 |
| Earth | 50 | 7290 | 31 |
| | 30 | 7671 | 39 |
| Earth | 30 | 17983 | 18 |
| | 20 | 23927 | 13 |
| Earth | 50 | 9525 | 34 |
| | 20 | 15469 | 25 |

NOTE: 1 km/hr =.62 mph, 1 mm = .04 in., 1 km = 0.62 mi.

Table 4. Roughness Values for Paved Sections

| Highway[a] Route Number | Mean[b] Roughness, mm/km | S. D. mm/km | C. V. % | Pavement[c] Type | PSR[d] | Age, Years |
|---|---|---|---|---|---|---|
| 1 (L) | 927 | 305 | 33 | 3 ST | 3.5 | 5 |
| 2 (L) | 1029 | 406 | 39 | 3 ST | 3.2 | 1 |
| - (L) | 231 | 76 | 33 | JCP | 4.0 | 0 |
| 107 (L) | 1212 | 592 | 49 | HMAC | 3.0 | 5 |
| - (L) | 2108 | 146 | 7 | JCP | 3.5 | 8 |
| 4 (C) | 1664 | 686 | 41 | HMAC | 2.4 | 30+ |
| 7 (C) | 813 | 508 | 63 | 3 ST | 3.0 | 7 |
| 401 (C) | 1803 | 330 | 18 | 3 ST | 2.3 | 3 |
| 4 (S) | 2718 | 1905 | 70 | 3 ST | 1.5 | 30+ |
| 4 (S) | 2997 | 2083 | 70 | 3 ST | 1.0 | 30+ |
| 7 (S) | 1245 | 711 | 57 | 3 ST | 2.8 | 10+ |
| 9 (S) | 381 | 229 | 57 | HMAC | 3.3 | 2 |
| 5050 (S) | 1067 | 864 | 81 | 3 ST | 2.5 | 10+ |

a. (L)-La Paz, (C)-Cochabamba, and (S)-Santa Cruz

b. Measured at 50 km/hr (30 mph)

c. ST - surface treatment, HMAC - hot mix asphaltic concrete JCP - jointed concrete

d. Present serviceability rating PSR by R. F. Carmichael
NOTE: 1 km = .62 mi., 1 mm = .04 in.

Table 5. Roughness Values for Gravel Sections

| Highway[a] Route Number | Mean[b] Roughness, mm/km | C.V. | Actual[c] Measurement Speed, km/hr | Highway[d] Type |
|---|---|---|---|---|
| 1 (L) | 8776 | 38% | 50 | P |
| 3 (L) | 7500 | 25% | 20 | P |
| 3 (L) | 6970 | 28% | 30 | P |
| 3 (L) | 12751 | 20% | 50 | P |
| 106 (L) | 7140 | 15% | 20 | S |
| 107 (L) | 9855 | 21% | 50 | S |
| 108 (L) | 12649 | 21% | 50 | S |
| 1350 (L) | 14986 | 22% | 50 | R |
| 4 (C) | 8179 | 23% | 50 | P |
| 7 (C) | 8001 | 34% | 50 | P |
| 106 (C) | 7990 | 31% | 30 | S |
| 401 (C) | 6630 | 17% | 20 | S |
| 4255 (C) | 5610 | 32% | 20 | R |
| 4 (S) | 10820 | 16% | 50 | P |
| 501 (S) | 4394 | 33% | 50 | S |
| 5050 (S) | 15596 | 11% | 50 | R |

a. (L)-La Paz, (C)-Cochabamba, (S)-Santa Cruz

b. Roughness values for 50 km/hr (30 mph)speed.

c. If measurement speed is less than 50 km/hr (30 mph) speed adjustment curves were used to obtain roughness value.

d. P - primary road, S - secondary road, and R - rural road
NOTE: 1 km = .62 mi, 1 mm = .04 in.

Table 6. Roughness Values for Earth Sections

| Highway[a] Route Number | Mean[b] Roughness, mm/km | C.V. | Actual[c] Measurement Speed, km/hr | Soil |
|---|---|---|---|---|
| 1355 (L) | 11390 | 31% | 50 | Clay |
| 1551 (L) | 8330 | 34% | 20 | Clay |
| 4255 (C) | 12410 | 19% | 20 | Rocky |
| 4791 (C) | 17983 | 18% | 30 | Organic with river gravel |
| 4767 (C) | 15011 | 14% | 30 | Organic with river gravel |
| 9 (S) | 16660 | 34% | 50 | Clay |
| 5260 (S) | 7747 | 29% | 30 | Sandy |
| 5134 (S) | 7600 | 34% | 20 | Sandy |
| 5030 (S) | 8500 | 36% | 20 | Sandy |
| 5115 (S) | 9017 | 64% | 30 | Sandy |

a. (L)-La Paz, (C)-Cochabamba, and (S)-Santa Cruz

b. All roughness values given for 30 km/hr.

c. If measurement speed is different than 30 km/hr speed adjustment curves were used.

NOTE: 1 km = .62 mi., 1 mm = .04 in.

Table 7. Effect of Grading on Gravel Sections

| Highway[a] Route Number | Before Grading[b] Roughness, mm/km | Before Grading[b] C.V. % | After Grading[b] Roughness, mm/km | After Grading[b] C.V. % | Actual[c] Speed, km/hr | Comments |
|---|---|---|---|---|---|---|
| 1 (L) | 17272 | 17 | 8306 | 11 | 50 | Same day |
| | | | 9627 | 12 | 50 | 24 hrs later |
| | | | 8255 | 17 | 50 | 48 hrs later |
| | | | 18288 | 10 | 50 | 20 days later |
| 1 (L) | 4318 | 27 | 2540 | 13 | 50 | Same day |
| | | | 3962 | 18 | 50 | 24 hrs later |
| | | | 10262 | 13 | 50 | 20 days later |
| 1350 (L) | 13843 | 14 | 8839 | 19 | 50 | Same day |
| | | | 12929 | 18 | 50 | 20 days later |
| 106 (L) | 6630 | 11 | 5270 | 7 | 30 | Alignment bad |
| 106 (C) | 7820 | 17 | 6460 | 20 | 20 | Too rough for 50 kmh |
| 4 (C) | 8179 | 23 | 8369 | 21 | 50 | No Difference |
| 4255 (C) | 5780 | 33 | 4250 | 34 | 30 | Alignment bad |

a. Districts are (L) - La Paz and (C) - Cochabamba.

b. All roughness values given for 50 km/hr speed.

c. If measurement speed is different than 50 km/hr speed adjustment curves were used.
NOTE: 1 km = .62 mi., 1 mm = .04 in.

Table 3. Effect of Grading On Earth Sections

| Highway[a] Route Number | Before Grading[b] Roughness, mm/km | Before Grading[b] C.V. % | After Grading[b] Roughness, mm/km | After Grading[b] C.V. % | Actual[c] Speed km/hr |
|---|---|---|---|---|---|
| 1355 (L) | 19000 | 29 | 6460 | 36 | 50 |
| 401 (L) | 12580 | 54 | 10540 | 37 | 20 |
| 4791 (C) | 18666 | 29 | 13668 | 21 | 30 |
| 9 (S) | 14960 | 18 | 11628 | 19 | 30 |
| 5030 (S) | 8874 | 39 | 6324 | 38 | 30 |
| 5134 (S) | 14892 | 21 | 7344 | 32 | 30 |
| 5260 (S) | 7480 | 32 | 4250 | 26 | 50 |

a. (L)-La Paz, (C)-Cochabamba, (S)-Santa Cruz.

b. All roughness values given for speed of 30 km/hr

c. If measurement speed is different than 30 km/hr speed adjustment curves were used.

NOTE: 1 km = .62 mi., 1 mm = .04 in.

Table 9. Comparison of Bolivia and Kenya Roughness Measurements

| Road Type | Bolivia Roughness Measurements Mean, (mm/km) | Bolivia Roughness Measurements Range, (mm/km) | Kenya Roughness Measurements Mean, (mm/km) | Kenya Roughness Measurements Range, (mm/km) |
|---|---|---|---|---|
| Paved | 1875 | 231 - 3600 | | |
| AC on Crushed Stone | | | 1814 | 1429 - 2697 |
| Surface Dressing on Cement Stabilized - New | | | 2415 | 1801 - 2918 |
| Surface Dressing on Cement Stabilized - Old | | | 2694 | 1877 - 3557 |
| Gravel | 13850 | 7000 - 22000 | 5984 | 22000 - 20600 |
| Good Condition | | | 5000 | |
| Poor Condition | | | 10000 | |
| Earth | 11465 | 7600 - 18000 | | |

NOTE: Kenya results are after Refs. 6, 8.

Table 10. TRRL Roughness Calibration (1978)

| TRRL Stage | Speed, km/hr | (a) 7/13/77 Mean Roughness, mm/km | (b) 3/03/78 Mean Roughness, mm/km | Percent Change of (a) and (b) | (c) 3/22/78 Mean Roughness, mm/km | Percent Change of (b) and (c) |
|---|---|---|---|---|---|---|
| | 50 | 7493 | 7042 | - 6 | 7142 | + 1 |
| 6 | 30 | 12271 | 11732 | - 4 | 11960 | + 2 |
| | 20 | 16898 | 17034 | + 1 | 19414 | +14 |
| | 50 | 6806 | 6385 | - 6 | 6274 | - 2 |
| 5 | 30 | 9338 | 9754 | + 4 | 9984 | + 2 |
| | 20 | 13646 | 13240 | - 3 | 14838 | +12 |
| | 50 | 5348 | 5174 | - 3 | 5270 | + 2 |
| 4 | 30 | 6639 | 6794 | + 2 | 6846 | + 1 |
| | 20 | 8684 | 9122 | + 5 | 10296 | +13 |
| | 50 | 4359 | 4133 | - 5 | 4108 | - 1 |
| 3 | 30 | 5432 | 5256 | - 3 | 5026 | - 4 |
| | 20 | 6823 | 6908 | + 1 | 7298 | + 6 |
| | 50 | 3135 | 3284 | + 5 | 3319 | + 1 |
| 2 | 30 | 3688 | 3406 | - 8 | 3432 | + 1 |
| | 20 | 4241 | 4312 | + 2 | 4212 | - 2 |
| | 50 | 1877 | 2002 | + 7 | 1924 | - 4 |
| 1 | 30 | 1504 | 1808 | +20 | 1734 | - 4 |
| | 20 | 1308 | 1538 | +18 | 954 | -38 |

NOTE: 1 km/hr = .62 mi/hr., 1 mm/km = .0667 in/mi.

Table 11. Paved Highways Roughness (1978)

| Highway[a] Route Number | Mean Roughness, 30 km/hr | Mean Roughness, 50 km/hr | Average C.V. % | Pavement[b] Type | Age Years |
|---|---|---|---|---|---|
| 1 (L) | 303 | 615 | 59.58 | 3 ST | 5 |
| 2 (L) | 770 | 1154 | 29.15 | 3 ST | 1 |
| 107 (L) | 608 | 984 | 71.64 | HMAC | 5 |
| - (L) | 1808 | 2052 | 22.09 | JCP | 8 |
| 4 (C) | 185 | 442 | 35.29 | 3 ST | 30+ |
| 4 (C) | 618 | 995 | 51.91 | HMAC | 2 |
| 4 (C) | 1357 | 1691 | 45.28 | HMAC | 30+ |
| 401 (C) | 914 | 1295 | 26.26 | 3 ST | 3 |
| 4 (S) | 2784 | 2745 | 63.53 | 3 ST | 30+ |
| 9 (S) | 110 | 311 | 76.53 | HMAC | 2 |
| 9 (S) | 112 | 314 | 53.01 | HMAC | 2 |

a. (L)-La Paz, (C)-Cochabamba, and (S)-Santa Cruz

b. ST - Surface Treatment, HMAC - Hot Mix Asphaltic Concrete, JCP - Jointed Concrete
NOTE: 1 km/hr = .62 mi/hr

Table 12. Gravel and Earth Roads Roughness In The Wet and Dry Seasons

| Highway[a] Route Number | Surface Type | Dry Season Roughness[b] Mean Roughness, mm/km | Dry Season C.V. % | Wet Season Roughness[b] Mean Roughness, mm/km | Wet Season C.V. % | Roughness Change, % |
|---|---|---|---|---|---|---|
| 1 (L) | Gravel | 8776 | 38 | 5837 | 29 | -33 |
| 3 (L) | Gravel | 7500 | 25 | 3795 | 40 | -49 |
| 3 (L) | Gravel | 12751 | 20 | 4621 | 27 | -64 |
| 106 (L) | Gravel | 7140 | 15 | 3385 | 25 | -53 |
| 107 (L) | Gravel | 9855 | 21 | 7184 | 29 | -27 |
| 1350 (L) | Gravel | 14986 | 22 | 5866 | 25 | -61 |
| 4 (C) | Gravel | 8179 | 23 | 7164 | 26 | -12 |
| 106 (C) | Gravel | 7990 | 31 | 5811 | 21 | -27 |
| 4255 (C) | Gravel | 5610 | 32 | 5662 | 13 | + 1 |
| 4 (C) | Gravel | 10820 | 16 | 6201 | 16 | -43 |
| 501 (S) | Gravel | 4394 | 33 | 3774 | 41 | -14 |
| 1355 (L) | Earth | 11390 | 31 | 5931 | 41 | -48 |
| 4255 (C) | Earth | 12410 | 19 | 10619 | 31 | -14 |
| 9 (S) | Earth | 16660 | 34 | 7676 | 53 | -54 |
| 5260 (S) | Earth | 7747 | 29 | 6089 | 69 | -21 |
| 5134 (S) | Earth | 7600 | 34 | 8280 | 36 | + 9 |

a. (L)-La Paz, (C)-Cochabamba, and (S)-Santa Cruz.

b. Roughness values given are for 50 km/hr on gravel roads and 30 km/hr on earth roads.
NOTE: 1 mm = .04 in., 1 km = .62 mi.

Table 13. Motograder Passes Effect on Reduction of Gravel and Earth Roads Roughness in the Wet and Dry Seasons

| Highway[a] Route Number | Surface Type | Dry Season Measurements: Before[b] Grading Roughness, mm/km | Dry Season Measurements: Effect of Motor Grader Passes, % | Dry Season Measurements: Time Lapse Grading/ Measurement | Wet Season Measurements: Before[b] Grading Roughness, mm/km | Wet Season Measurements: Effect of Motor Grader Passes, % | Wet Season Measurements: Time Lapse Grading/ Measurement |
|---|---|---|---|---|---|---|---|
| 1 (L) | Gravel | 17272 | - 52 | Same day | 5388 | - 24 | Same day |
| | | | - 44 | One day | | - 25 | 14 days |
| | | | - 52 | Two days | | | |
| | | | + 6 | 20 days | | | |
| 1 (L) | Gravel | 4318 | - 41 | Same day | 6164 | - 38 | Same day |
| | | | - 8 | One day | | - 5 | 14 days |
| | | | +138 | 20 days | | | |
| 3 (L) | Gravel | | | | 3795 | - 13 | Same day |
| 3 (L) | Gravel | | | | 4575 | - 18 | Same day |
| 106 (L) | Gravel | 6630 | - 21 | | 3544 | - 19 | Same day |
| 106 (C) | Gravel | 7820 | - 17 | | 5568 | - 14 | Same day |
| | | | | | | - 3 | Eight days |
| 501 (S) | Gravel | | | | 4885 | - 1 | Same day |
| 9 (S) | Earth | 14960[c] | - 22 | | 4960[c] | - 30 | Same day |

a. Districts are (L) - La Paz, (C) - Cochabamba, and (S) - Santa Cruz

b. Roughness values given for 50 km/hr speed

c. Roughness values for 30 km/hr speed

NOTE: 1 mm = .04 in., 1 km = .62 mi.

Figure 1. Location of Roughness Measurements


Figure 2. Speed Correction Relationships

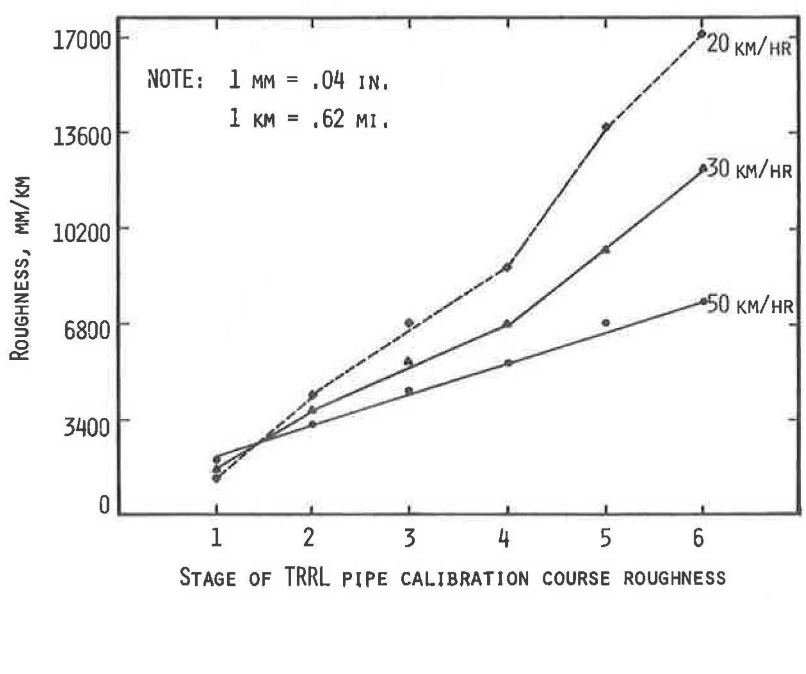


Figure 3. Roughness Versus Speed for Inservice Roads

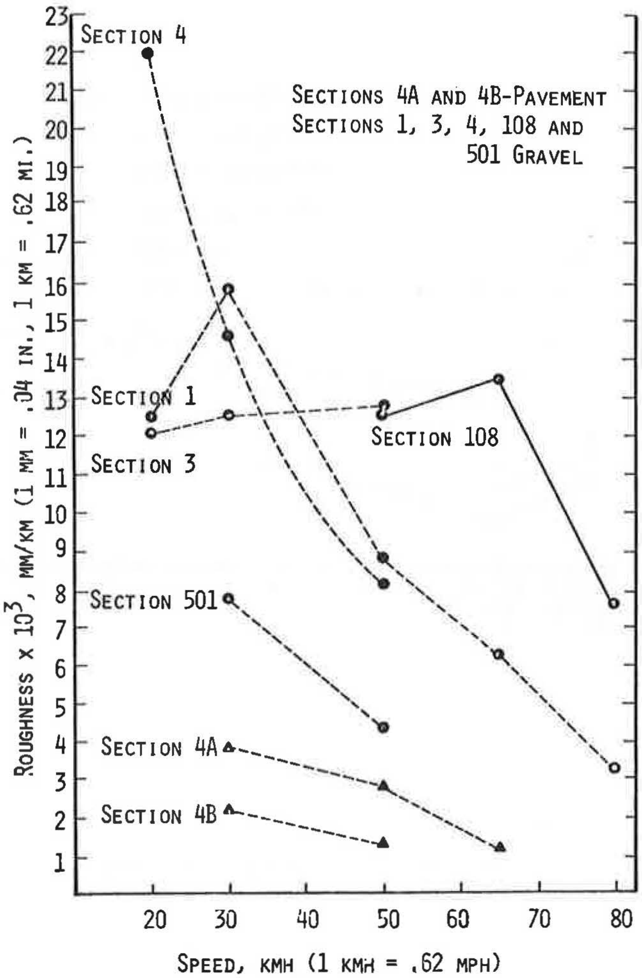



Figure 4. Present Serviceability Rating Versus Roughness for Paved Roads

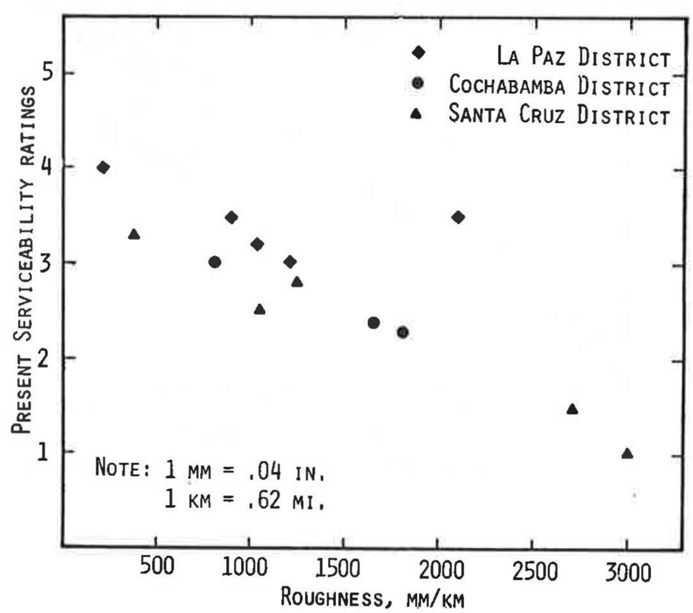


Figure 5. Roughness Versus Time for Gravel Grading Sections

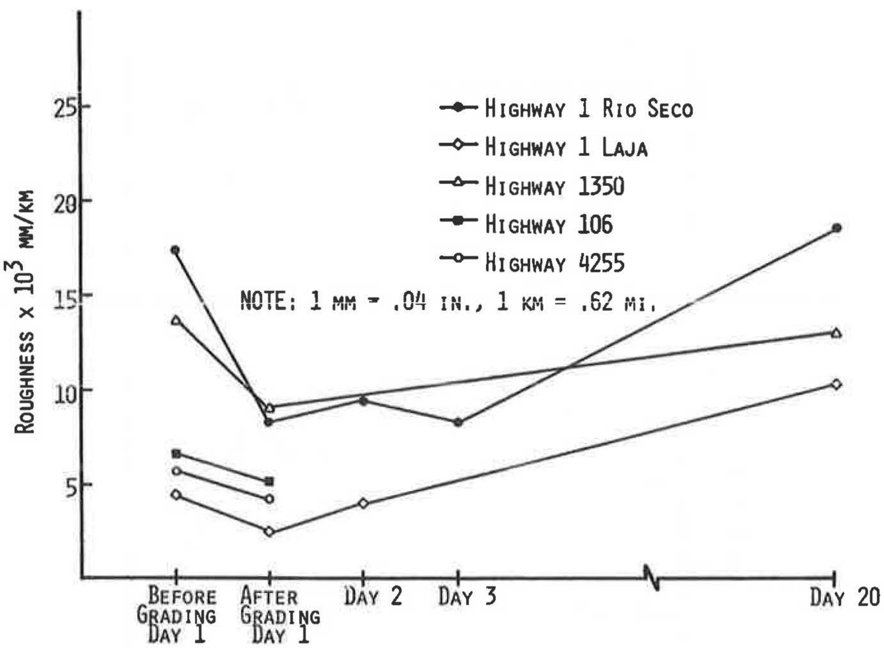
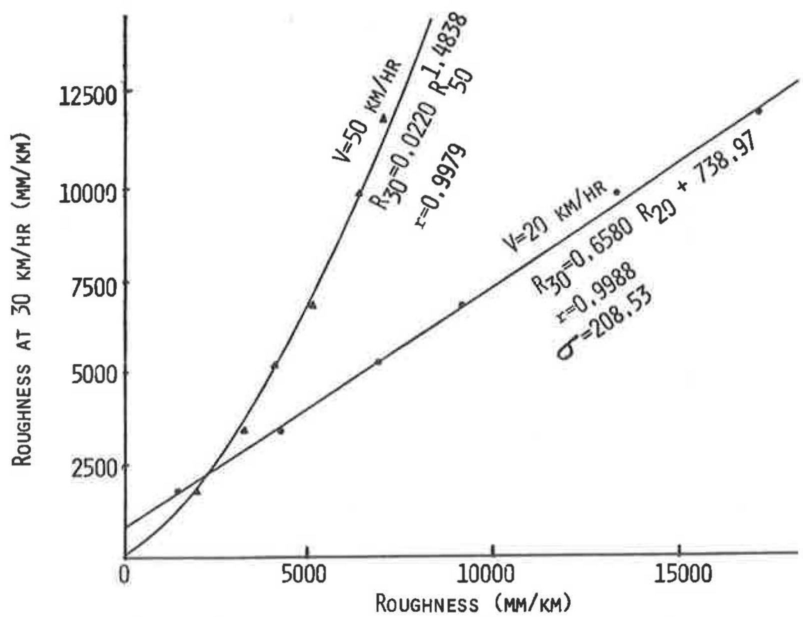



Figure 6. Roughness at 30 km/hr Versus Roughness at 20, 50 km/hr




Note: Measurements taken on TRRL Calibration Course.